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Integrated Atmosphere Resource Recovery and Environmental Monitoring Technology Demonstration for Deep Space Exploration

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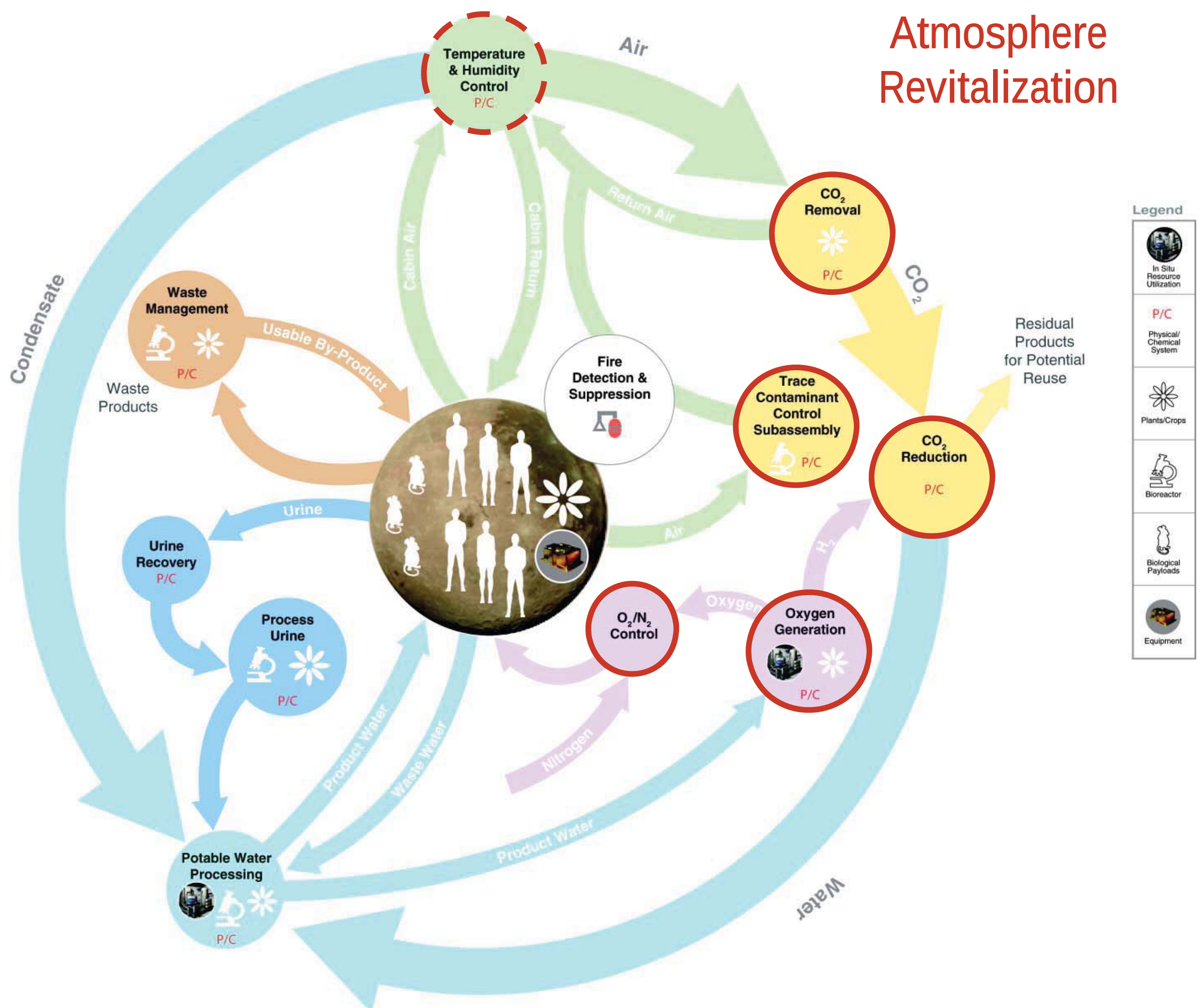
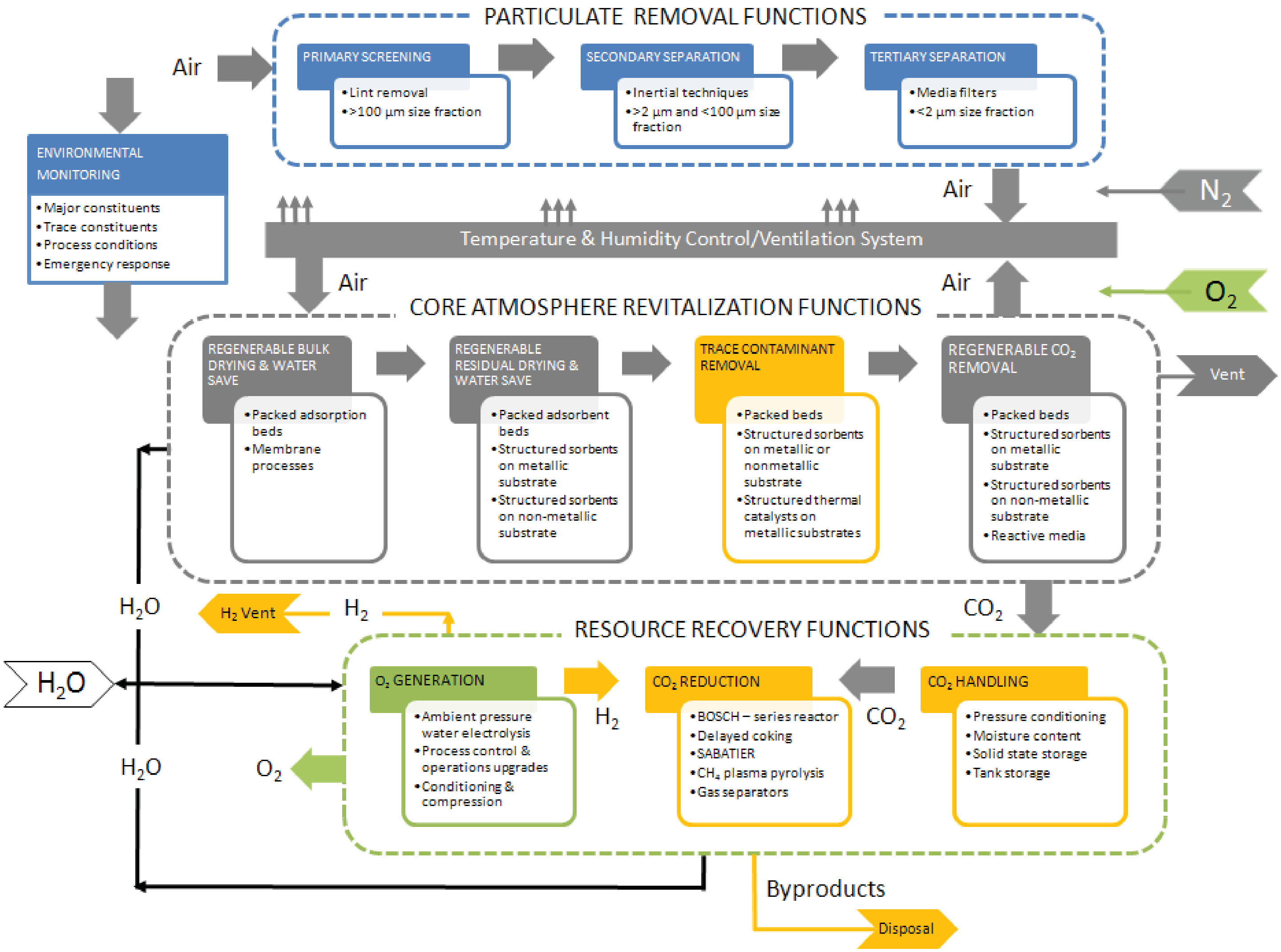
Technological Advancement Objectives

- To evolve the ISS environmental control and life support (ECLS) system platform to enable deep space exploration
  - Improve reliability & maintainability
  - Reduce consumable mass
- To maximize commonality across missions and vehicles
- To mature process technologies for flight programs
  - Reduce technical risk and cost
- To develop modular resource recovery technologies

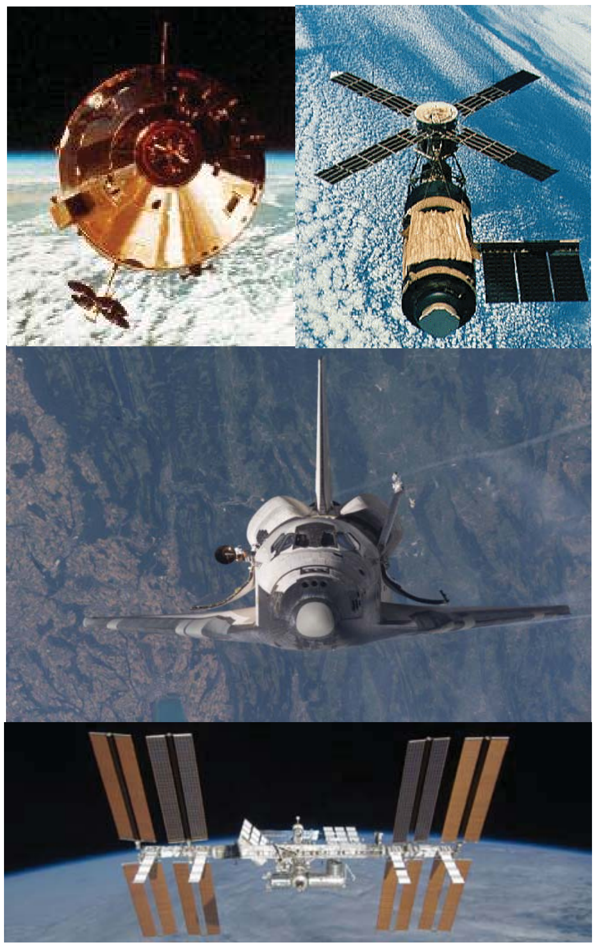
What is Atmosphere Revitalization?



Functional Trade Spaces Help Focus Development



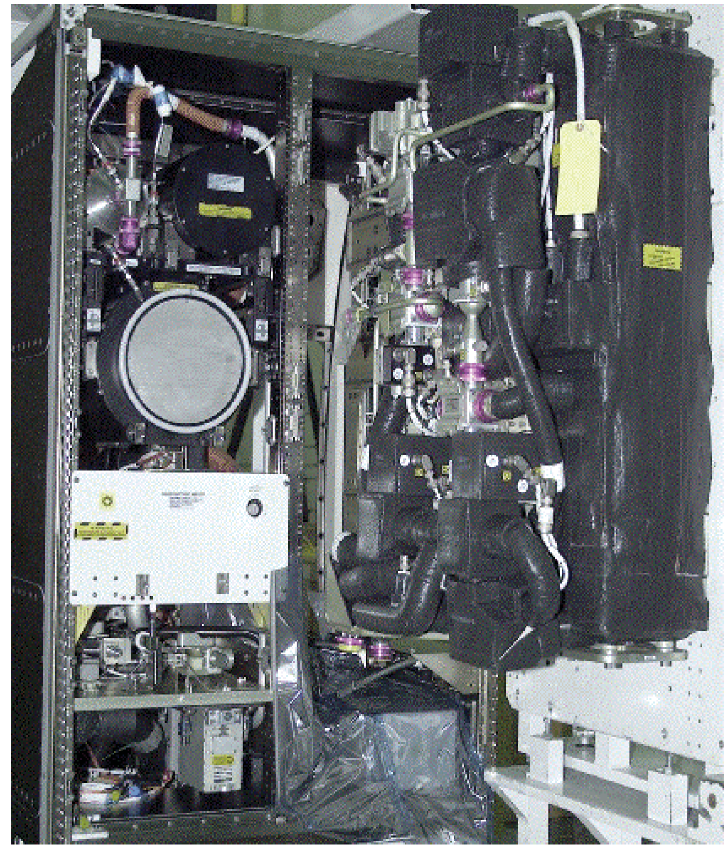
Spacecraft Atmosphere Revitalization Past & Present



PROJECT	MISSION DURATION	CABIN VOLUME (m^3)	CREW SIZE	TECHNOLOGICAL APPROACH
Mercury	34 hours	1.56	1	**Atmosphere:** 100% O_2 at 34.5 kPa. **Atmosphere supply:** Gas at 51.7 MPa. **CO_2 removal:** LiOH. **Trace contaminants:** Activated carbon.
Gemini	14 days	2.26	2	**Atmosphere:** 100% O_2 at 34.5 kPa. **Atmosphere supply:** Supercritical storage at 5.86 MPa. **CO_2 removal:** LiOH. **Trace contaminants:** Activated carbon.
Apollo	14 days	5.9	3	**Atmosphere:** 100% O_2 at 34.5 kPa. **Atmosphere supply:** Supercritical storage at 6.2 MPa. **CO_2 removal:** LiOH. **Trace contaminants:** Activated carbon.
Skylab	84 days	361	3	**Atmosphere:** 72% O_2/28% N_2 at 34.5 kPa. **Atmosphere supply:** Gas at 20.7 MPa. **CO_2 removal:** Type 13X and 5A molecular sieves regenerated by vacuum swing. **Trace contaminants:** Activated carbon.
Space Shuttle	14 days	74	7	**Atmosphere:** 21.7% O_2/78.3% N_2 at 101 kPa **Atmosphere supply:** Gas at 22.8 MPa **CO_2 removal:** LiOH **Trace contaminants:** Activated carbon and ambient temperature CO oxidation
International Space Station	180 days	Up to 600	3 to 6	**Atmosphere:** 21.7% O_2/78.3% N_2 at 101 kPa **Atmosphere supply:** Gas at 20.7 MPa/water electrolysis **CO_2 removal:** Silica gel with type 13X and 5A molecular sieves regenerated by vacuum/temperature swing **CO_2 reduction:** Sabatier reactor (scar for future addition) **Trace contaminants:** Activated carbon and thermal catalytic oxidation

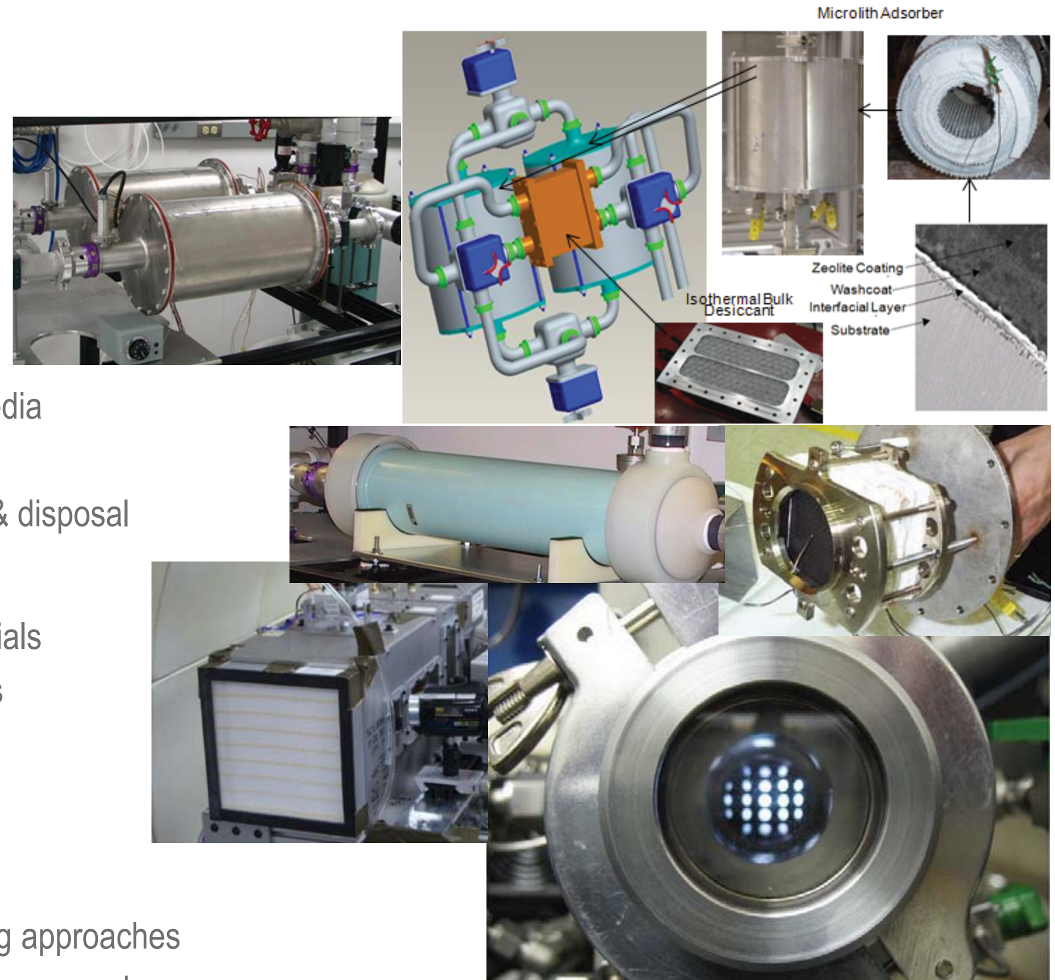
ISS – The “Launch Platform” to Deep Space

- Reduce:
  - Logistics requirements
  - Expendable resources
  - Complexity
- Improve:
  - Operational robustness
  - Life cycle economics
- Demonstrate:
  - More complete loop closure

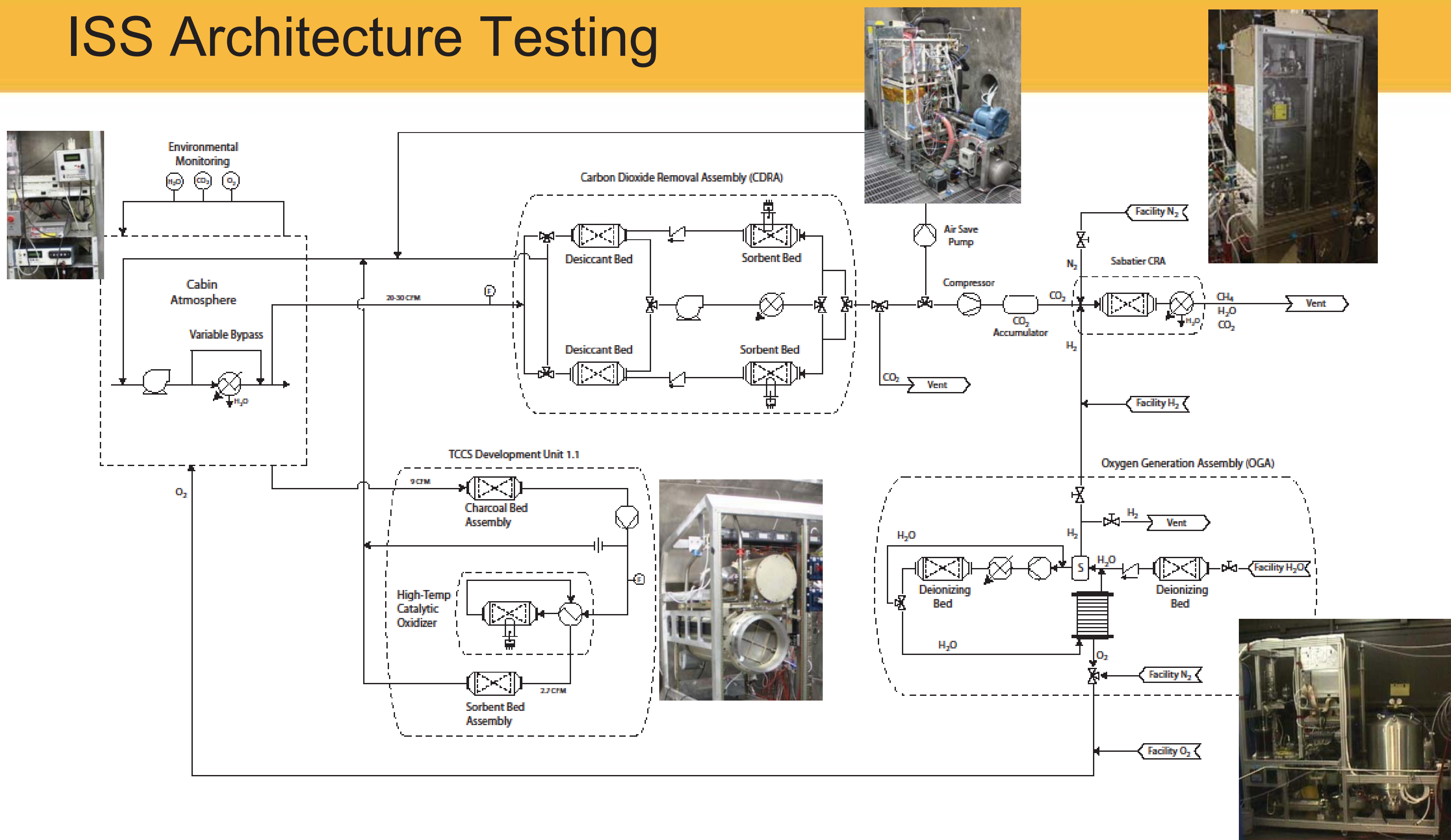


Strategic Improvements

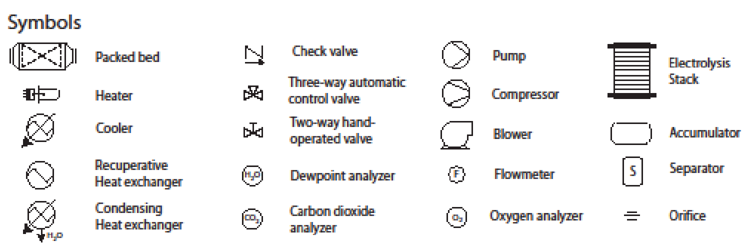
- Cabin ventilation
  - Quiet fan design principles
- Carbon dioxide removal
  - Durable adsorbent media
  - Process air drying
- Trace contaminant control
  - Alternative high capacity adsorbent media
  - Structured oxidation catalysts
  - Low maintenance particulate filtration & disposal
- Oxygen supply
  - Long-lived electrolysis cell stack materials
  - Alternative process control approaches
- Oxygen recovery
  - Reduction byproduct processing
- Environmental monitoring
  - Alternative major constituent monitoring approaches
  - Alternative trace constituent monitoring approaches
  - Microbial & particulate monitoring techniques



ISS Architecture Testing



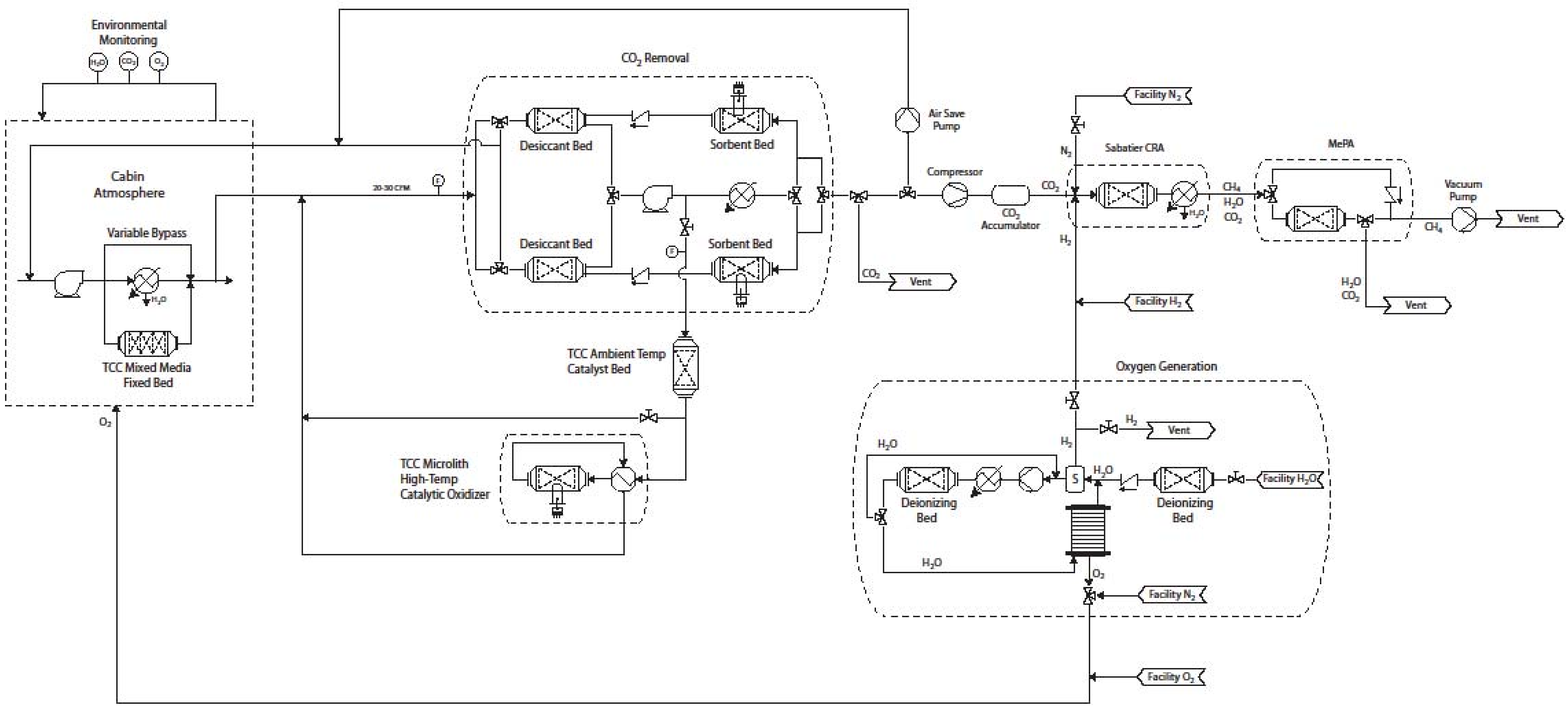
ISS Performance Basis
Hardware Schematic
Draft 4
5-15-2012



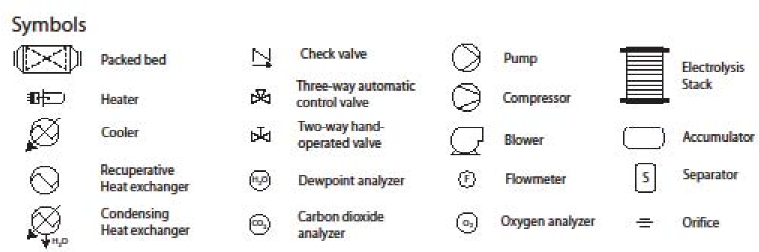
ISS Architecture Testing Objectives

- Phase 1A—Demonstrate functional performance of the basic ISS AR subsystem using the CDRA in CO_2 vent mode and the TCCS operating in parallel.
- Phase 1B—Demonstrate the partial functional performance of the basic ISS AR subsystem when operating in a resource recovery mode that includes integration with CO_2 conditioning, storage, and reduction equipment.
- Phase 2 —Investigate propagation of trace contaminants through the core ISS AR subsystem equipment with emphasis on the CDRA and CO_2 conditioning and storage equipment.
- Phase 3—Demonstrate the full resource recovery functional performance of the ISS AR subsystem including the CO_2 removal, CO_2 conditioning and storage, CO_2 reduction and post-processing, oxygen generation, and trace contaminant control functions.

Cycle 1 Integrated Process Architecture



Integrated Systems Test #1
Hardware Schematic
Draft 7
5-15-2012



Cycle 1 Testing Objectives

- Demonstrate simultaneous sustained operation of oxygen generation, CO_2 removal, trace contaminant control, major constituent monitoring, and CO_2 reduction processes under continuous operating conditions using an ISS-derived process architecture.
- Demonstrate the effect of the control algorithm governing the CO_2 compressor operation (on/off rules) and the CDRA valve sequencing on the overall CO_2 reclamation efficiency for various modes of operation.
- Determine the purity of product CO_2 from the CDRA-4 sorbent beds.
- Determine the purity of product oxygen and hydrogen from the OGA.
- Determine the effect cabin atmosphere leakage and/or atmospheric major constituent inclusion on the CDRA CO_2 product may have on CRA performance.
- Determine the purity of product water from the Sabatier-based CRA.
- Demonstrate CRA post-processing first stage to purify methane.
- Demonstrate oxygen generation alternative process control concept.

Incremental Process Architecture Progression

- Cycle 1: Modified ISS architecture incorporating improved trace contaminant and CO_2 removal adsorbents; trace contaminant removal oxidation catalysts; partial CO_2 reduction byproduct processing; and alternative major atmospheric constituent monitoring.
- Cycle 2: Alternative process gas drying equipment; advanced CO_2 reduction byproduct processing; and alternative major constituent and volatile organic compound monitoring.
- Cycle 3: Advanced CO_2 removal and compression; complete CO_2 reduction byproduct processing; advanced environmental monitoring sensor array; ammonia catalytic reduction.

Conclusion

- Functional, unit operation-driven approach
  - Focus on ISS ECLS system strengths and weaknesses
  - Use robust design principles to achieve stage-wise optimization
- Leverage core process technologies from existing equipment designs as appropriate
- Attention to design modularity to address commonality across mission and vehicle architectures

Further Reading

- Perry, J.L., Carrasquillo, R.L., and Harris, D.W. (2006) Atmosphere Revitalization Technology Development for Crewed Space Exploration. 44th AIAA Aerospace Sciences Meeting and Exhibit. AIAA-2006-140. Reno, Nevada, January 2006.
- Perry, J.L. (2007) Atmosphere Revitalization--Process Technology Maturation for NASA's Constellation Projects. Space Technology and Applications International Forum (STAIF 2007), Albuquerque, New Mexico, February 2007.
- Perry, J.L. and Howard, D.F. (2007) Spacecraft Life Support System Process Technology Maturation using Stage Gate Methodology. 37th International Conference on Environmental Systems. SAE 2007-01-3045.
- Perry, J.L., Bagdigian, R.M., and Carrasquillo, R.L. (2010) Trade Spaces in Crewed Spacecraft Atmosphere Revitalization System Development. AIAA-2010-6061, 40th International Conference on Environmental Systems, Barcelona, Spain.